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Ultrafast Thermal Cycling of Solar Panels

15 August 1998

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Two new cyclers that utilize a novel hybrid approach to perform fast thermal cycling of solar panels have been built and are now operational in the Mechanics and Materials Technology Center at The Aerospace Corporation. These cyclers are part of a continuing effort to minimize solar cell life test durations by accelerating the cycling rates. These fully automated cyclers, which provide continuous unmanned cycling in a gaseous nitrogen atmosphere, can execute 5 min cycles, thus yielding in excess of 100,000 cycles per year. They also have a unique capability of verifying solar panel functionality without interruption of cycling, so that cycling doesn't continue on nonfunctioning panels.

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Preface

The authors express their thanks to R.W. Francis of the Electrical and Electronic Systems Department and R.B. Pan of the Mechanical Components Department for the opportunity to develop and improve solar cell cyclers over the years.

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1. Introduction

In order to validate solar cell panel designs in a more timely manner, two new fast cyclers have been built and are now operating in the Mechanics and Materials Technology Center (MMTC) at The Aerospace Corporation. In the past, the design validation process has been the most prevalent bottleneck encountered in the development of new solar cell designs for critical mission applications. The resulting customer demand to acquire desired thermal cycles before urgent launch deadlines spurred on our efforts to accelerate cycling rates for panel validation. We have employed a number of methods to accomplish this acceleration during the evolution of our cycling facilities over the last 14 years, culminating in our most recent cycler design.

2. Earlier Cycler Designs

2.1 A Conductive Cycler

In 1984, a conductive thermal cycler was constructed at Aerospace to perform life tests on the new generation of Defense Meteorological Satellite Program (DMSP) GaAs solar cells. Cycling is achieved by cooling a fairly massive aluminum plate with counter-flowing liquid nitrogen (LN_2), then heating the plate with symmetrically embedded electric rod-heaters. The test articles are held in contact with the plate so that cycling occurs primarily by conduction. Typical solar cell arrays mounted on lightweight 1/4-in.-thick honeycomb panels generally require 60–90 min to cycle ±80.0°C while under 1×10^{-7} Torr vacuum.

The conductive cycler is still available and is well suited for vacuum cycling of cells mounted on heavy 1/8-in.-thick solid aluminum panels, which have been quite common in the past. Note that the disadvantage of this cycler in terms of cycling rates is that the heat and cool phases work against each other in driving the conductive plate.

2.2 Radiant Cyclers

In 1990, the first radiant thermal cycler was brought into service at Aerospace. This cycler utilizes quartz-halogen lamp radiation in a vacuum with a surrounding cold shroud for heat absorption to cycle the cells, as opposed to the direct conduction method employed by the conductive cycler. Cycle periods of 30 to 60 min were attainable on comparable lightweight 1/4-in.-thick honeycomb panels. A second cycler of this kind was made available in 1993 to meet new customer demands. However, because these cyclers depend solely on radiation in a vacuum, only articles of very low mass can be rapidly cycled.

These cyclers are still operational and are well suited for vacuum cycling thin, lightweight specimens with large surface areas. Note that only the heat phase works against the cool phase in these cyclers, which is an advantage over the conductive cycler in terms of cycling rate. The heating lamps immediately overcome the cooling shroud effects in the heat phase, but in so doing, warm the shroud significantly. The shroud can only recover during the next cool phase, even though it is being filled with LN_2 during the heat phase.

In 1996, a novel method of optimizing the cooling rate for these two radiant thermocyclers was employed. By the introduction of just the right nitrogen partial pressure inside the vacuum chamber, the conduction of heat from the coupons to the cold shroud via the nitrogen assisted the cooling. This was done without significant degradation of the radiant cooling contribution. The result was a net increase in the cooling rate. It was experimentally demonstrated that a significant improvement in the cooling rate was achieved by maintaining a 40 mTorr nitrogen pressure during the cool phase. This pressure yielded shorter cycle periods of 22 to 45 min on comparable lightweight 1/4-in.-thick honeycomb panels. Note that the following disadvantages remain: the heat phase still works against the cool phase in these radiant cyclers, and only panels of very low mass can be cycled rapidly.

3. A New Hybrid Design

In the latest endeavor at Aerospace to maximize cycling rates, we employ a combination of the best aspects of all of our previous cyclers along with the lessons learned. Figure 1 shows the new hybrid cycler. We utilize a chamber filled with nitrogen gas. In this chamber, a solar array panel is transported between a hot compartment in the top and a cold compartment in the bottom. The chamber is constantly pressurized with ultrapure nitrogen gas to slightly above ambient atmospheric pressure, with the gas being vented out the top of the chamber by adjustable vent valves. A motor/pulley/cable system raises and lowers the panel under test along a vertical track joining the two compartments. The entire chamber is insulated, so that these two compartments are thermally isolated from one another, except for the opening between them.

The major advantage of this design over that of the previous cyclers is that the cool phase and heat phase no longer work against each other. One compartment is able to fully recover while the other compartment is in use. The chamber accommodates a 1 ft^2, 1-in.-thick curved fiberglass panel with an aluminum honeycomb filler. This panel is substantially more massive than the typical solar cell arrays cycled in the former facilities.

Four sets of two quartz-halogen infrared (IR) heating lamps located in the top compartment surround the panel in the heat phase and maintain the upper compartment at an elevated temperature, so that the panel is warmed by both radiation and gaseous conduction. The panel is lowered into the bottom compartment for the cool phase, where the surrounding walls are maintained at extremely low temperatures by LN_2 in an outer container. The panel is cooled by both radiation to the cold walls and gaseous conduction. The upper heating compartment is maintained at a high temperature during the cool phase, while the cooling shroud outer container is filled with LN_2 during the heat phase, so that neither compartment expends any time recovering during its use. These systems can thereby yield 5–10 min cycle periods in a gaseous nitrogen environment for the new qualification panels.

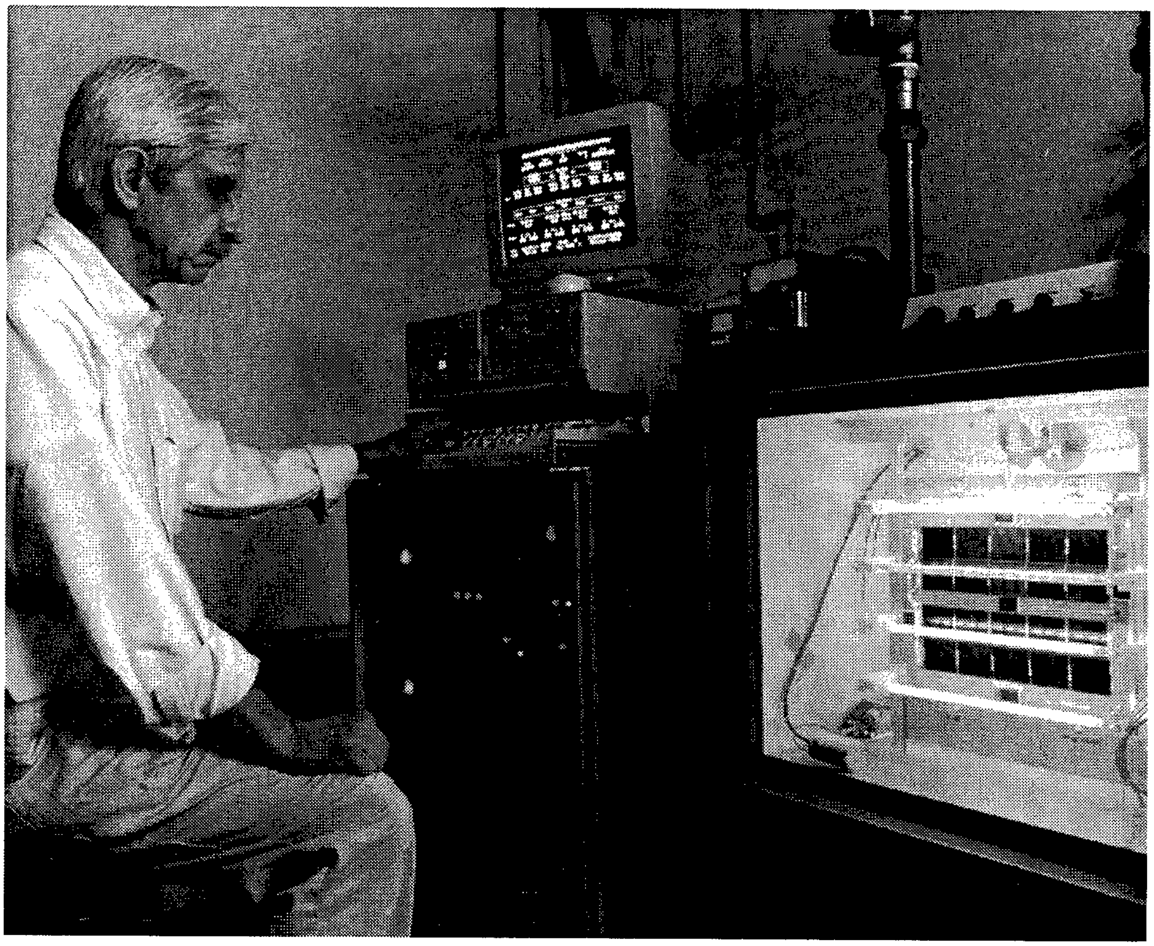


Figure 1. Fast solar panel thermal cycler.

4. The Thermal Cycle Process

Figure 2 shows a cycle profile for a panel with a cycle period under 4 min. This is one of the fastest cycling rates achieved in the fast cycler to date. However, this is not a typical thermal cycle, since there is no dwell at the top of the heating phase and the thermal rates were not purposely limited.

Figure 3 shows a typical cycle profile for a panel having a 1 min dwell. The cycle period is just under 10 min, by customer request, in order to avoid exceeding their specific panel design thermal rate limits. As illustrated, a typical complete cycle consists of a heat phase, a heating-dwell phase, and a cool phase. A detailed explanation follows of the processes involved in a typical thermal cycle.

4.1 Heat Phase

The heat phase employs four sets of two stationary quartz-halogen IR lamps positioned horizontally on either side of the panel in the top compartment. Thermocouples (TCs) are mounted on the panel so that they are directly in line with the first set of lamps at the top, between the two middle sets, and directly in line with the last set of lamps at the bottom, when the panel is suspended in its proper heating phase position. These three TCs, together with the lamp currents, provide feedback for thermal control, as well as customer data logging.

4.1.1 Heating Fail-Safe

The normal resting position for the panel is between the lamp sets in the top compartment, which is the heating position. Any time power or control for the facility is interrupted, a fail-safe procedure drops power to the motor. A counterweight pulls the panel up into this safe "home" position, and the lamps keep the panel warm (approximately 40°C) with low Variac power supplied from an uninterruptible power supply (UPS).

4.1.2 Heating Phase Control

Upon entry of the panel to each new heating phase, the four lamp sets are first equalized to a preset current, which will determine the maximum heating rate for the entire phase. Then the lamp currents for the two midlamp sets are linearly ramped up to a second current level in proportion to the midpanel temperature, reaching the maximum current at the customer's heating extreme. At the same time, power for the top and bottom lamp sets is proportionately controlled as a function of the difference between each lamp set's corresponding TC and the midcontrol TC. This control of power ensures that the top and bottom panel temperatures are slaved to track the midcontrol TC. In this manner, the panel temperatures climb together to the target temperature, with no thermal gradients across the panel and with excellent repeatability.

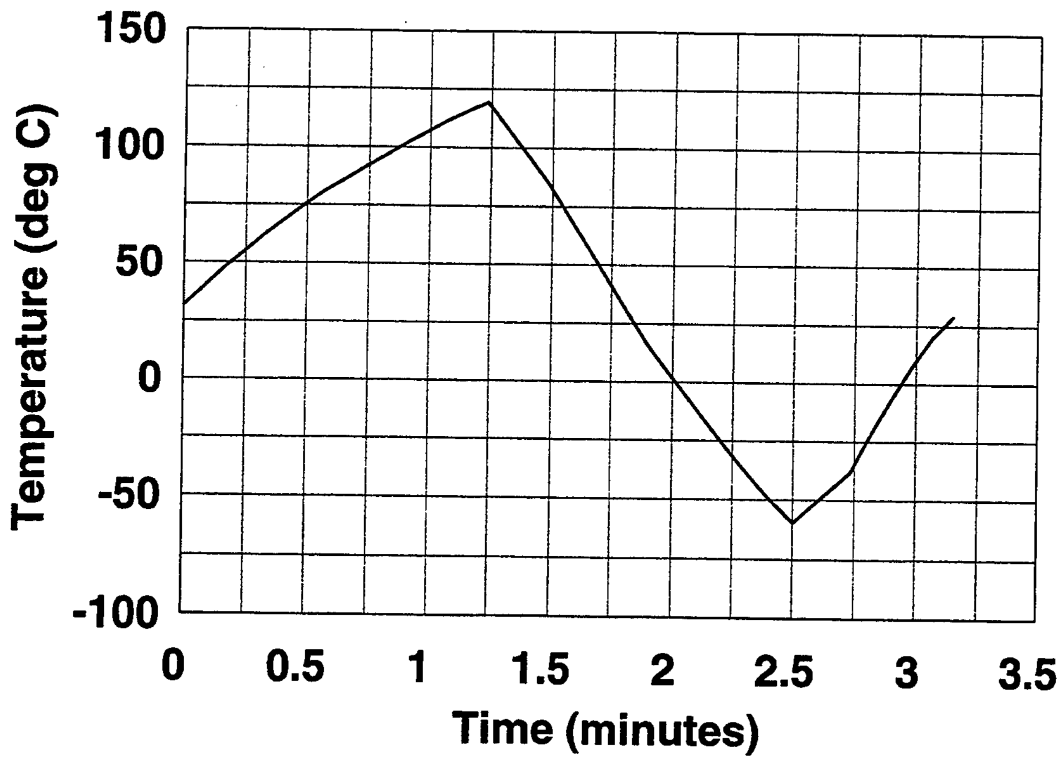


Figure 2. Fast thermal cycle.

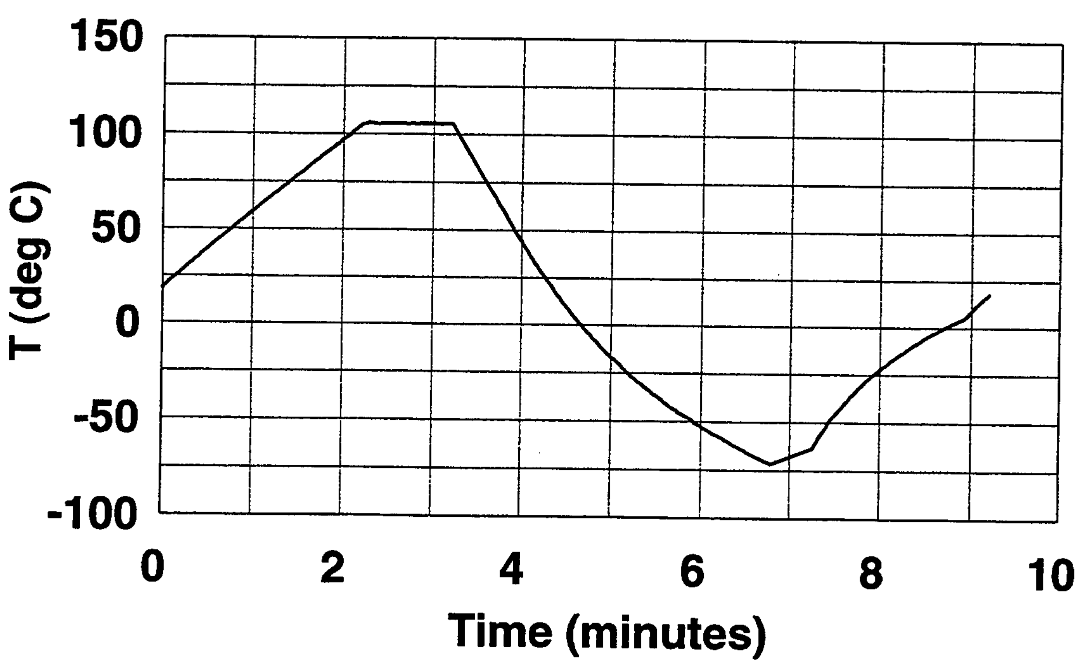


Figure 3. Typical thermal cycle profile–cycle 25000.

4.1.3 Heating Overshoot Control

In actual operation, the thermal inertia of the solar panel arising from accelerated heating rates can result in excessive overshoots at the heating extreme. To avoid these overshoots, the control TC converges toward a variable temperature target below the desired extreme by evaluating the last cycle's performance and adjusting the target accordingly. This technique continually corrects for any changes in ambient temperature or for other influences that affect thermal overshoot or undershoot. In addition, this technique ensures that the TC will tend to consistently meet the customer's desired cycling extreme. When the midcontrol TC reaches this variable target extreme, the heating-dwell phase is initiated.

4.2 Heating-Dwell Phase

In the heating-dwell phase, the panel remains in the "home" position between the IR lamps in the top compartment, where the lamps maintain the panel at the heat phase extreme. It is very common for a customer to request a programmed dwell period in the heating phase. A thermal "soaking" period at the heating extreme helps to ensure that the entire panel comes to a constant temperature free from gradients. The dwell period can also emulate actual conditions the customer expects the flight panel to experience in a given application. Since the dwell phase holds the panel at the most constant temperature in the cycle, it also lends itself to be used to perform any tests on the panel that might be temperature dependent.

4.2.1 Dwell In-Situ Tests

We developed a new capability for this test facility in response to an additional cycling requirement requested by the customer. Since panels are typically removed for elaborate solar-simulator performance evaluations after every 5000 cycles or more, it was desirable to verify that the cells were still functional without interrupting cycling or removing the panel. Therefore, we implemented a scheme to perform fully automated in-situ bypass diode tests and current tests alternately every 10th cycle. In this scheme, we injected known currents into the solar cell circuit and measured the corresponding voltages produced across the cells. Because these measurements are panel temperature dependent, they were taken during the dwell phase.

These solar cell performance and interconnect integrity checks provide indicators to allow for immediate test termination in the event of cell degradation or failure. These indicators promote the discovery of failure mechanisms, contribute to more accurate panel survival data, and save qualification time by terminating the cycling of damaged cells. Figures 4 and 5 are the characteristic bypass diode test and current test results, respectively, obtained by this new method.

4.2.2 Dwell Phase Control

A timed dwell of a minute or longer permits the current tests to be performed. The first 30 sec allows the panel to come to thermal equilibrium. Then, a programmable current source linearly ramps the current through the cells up to 0.200 A in 10 sec, and holds the current constant for 10 sec. Next, the voltage across the cells is recorded, and the current is ramped down to zero in 10 sec. Both the current and the bypass diode tests are identical, except for the direction of the applied current. Once the remainder of the dwell time has expired, the motor transports the panel from its "home" position in the top compartment to a predetermined position in the bottom compartment, where the cool phase begins.

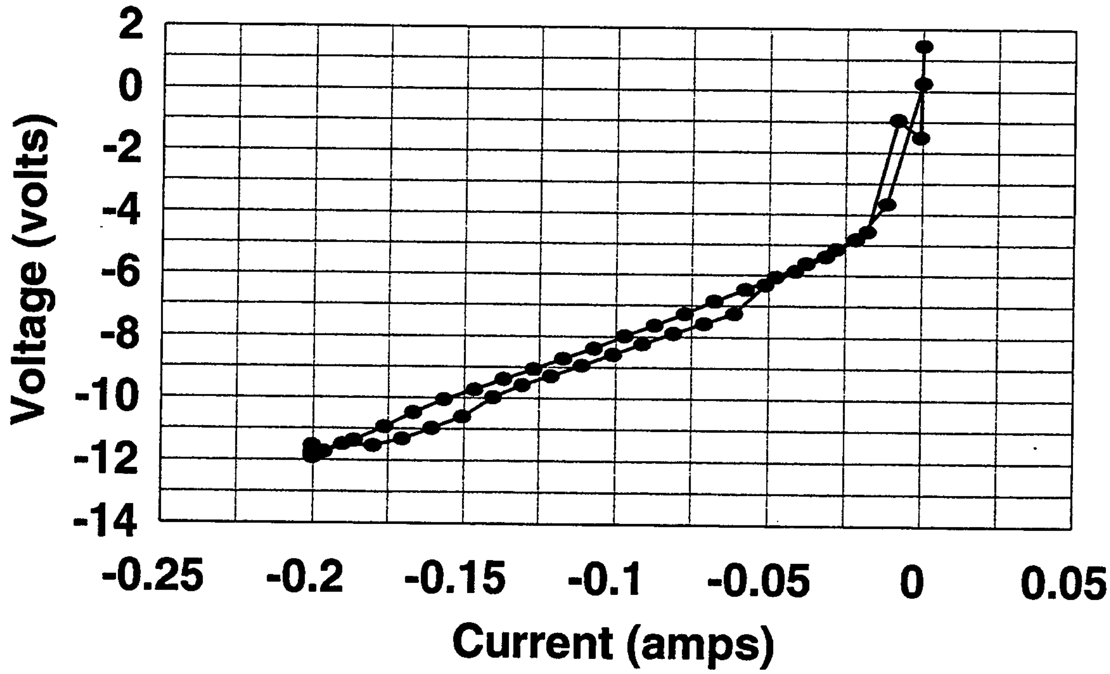


Figure 4. Bypass diode test–cycle 25000.

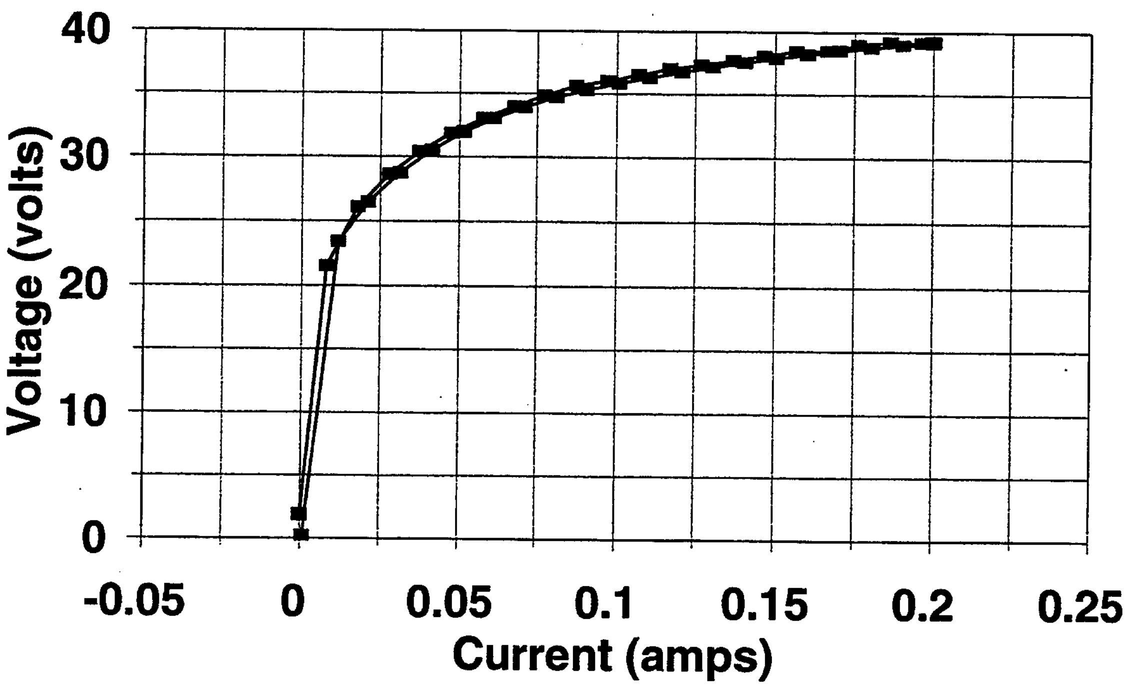


Figure 5. Current test–cycle 24990.

4.3 Cool Phase

Cooling is accomplished in the bottom compartment using a surrounding shroud maintained at -188°C by filling its outer jacket with LN_2. As LN_2 in the outer jacket gassifies, this gas is directed into the cooling compartment through holes strategically placed along the top of the compartment. The very cold, dry nitrogen gas is comparatively heavy, and so tends to flow down into the cooling compartment and surround the solar panel under test. Thus, the panel is never in direct contact with LN_2. An external gaseous nitrogen purge is also introduced into the bottom of the compartment during the cool phase, to promote a more homogenous thermal mixture. This purge is used in addition to the constant chamber pressurizing purge delivered into the upper compartment.

4.3.1 Cooling Edge-Effects

The solar panel under test is instrumented with three control TCs and three spares for redundancy and corroboration. A control and a spare TC are located at the top edge, at the bottom edge, and at the exact middle of the panel, respectively. Due to thermal edge-effects, the panel will always tend to get colder more quickly along its bottom and top edges than in the middle during the cooling phase. This tendency creates thermal gradients across the panel. To compensate for this effect along the bottom edge of the panel, a stationary IR lamp in the bottom of the cooling compartment is energized during the cooling phase. The edge-effect is countered at the top edge by how far the panel is allowed to travel into the cooling compartment. Note that thermal gradients can increase dramatically with accelerated cycling rates, and a common solution in the thermal cycling industry is to ignore the problem by using only one control TC in the middle of the coupon for customer data logging.

4.3.2 Cooling Phase Control

At the end of the heat-dwell phase, the edge-effect cool lamp is energized, the nitrogen cooling purge begins, and the motor transports the panel from its "home" position in the top compartment to a predetermined position in the bottom compartment, where cooling begins. The panel is cooled by the cold nitrogen gas and by radiation to the surrounding cold shroud. Both the cool-lamp current (heating the panel's bottom edge) and the panel excursion position (affecting its top edge) are programmed to converge to values such that both the top and bottom panel temperatures equal the midpanel temperature at the instant the midpanel reaches the cooling target extreme. Since these values are determined by the results of the preceding cycle, the control system constantly compensates for slowly changing environmental influences.

4.3.3 Cooling Undershoot Control

Similar to the heat phase, the accelerated cooling rates can result in the panel dropping significantly below the cool target extreme at the transition from cooling to heating. This tendency is corrected for by programming the control TC to converge toward a variable temperature target above the desired extreme. The target is determined by evaluating the preceding cycle's performance and adjusting the target accordingly, thereby continually correcting for influences affecting this transition. When the midcontrol TC reaches this variable target extreme, the cool lamp and nitrogen purge are turned off, and the panel is transported back to the "home" position in the top compartment, where the heat phase is re-initiated and the next thermal cycle begins.

5. Monitoring, Control, and Fail-Safe Systems

A 486-66 MHz computer is used as a front-end controller to fully automate the cycler, enabling it to provide continuous long-term, unattended fail-safe thermal cycling. An interactive user interface on the monitor's screen allows the user to view cycle indicators and to alter control values without interrupting cycling in progress. Specialized program code written in compiled Basic and C++ performs data acquisition, fail-safe thermal cycle control, and data archiving, and monitors critical processes looking for anomalies.

The system's primary functions ensure the protection of personnel, equipment, and solar cells under test. An alarm monitor, operating independently of the computer, automatically notifies the operator in response to signals initiated by the computer, a computer latch-up, or loss of power. Remote computer links permit the user to modify control parameters and to correct problems from off-site. These remote links are especially important during the crucial beginning phase of a life test, where panel cycling behavior must be fully characterized before the optimum control criterion can be determined. Specialized program control routines usually must be introduced for each new panel design, and then for converging to the best operational parameters for that design.

5.1 On-Screen Operator Interface

General test logistics, such as the time, date, cycles completed, and a test-file name, are displayed on the main screen. The test file has a unique time/day/year formatted name. New cycle data are appended to this file every cycle to characterize and archive each cycle's behavior. A motor control panel on screen displays the solar panel's position and enables manual motor excursion control. The ongoing solar cell panel temperatures are displayed, along with the "max" and "min" temperature extremes encountered up to that point during the current cycle. Also shown on the main screen are the "max" and "min" temperatures existing at the moment of the heating and cooling phase transitions for the last cycle. These temperatures are used by the control code to converge to the mandated target temperatures. The panel heating process using the IR lamps is also depicted, showing the immediate output control settings for each lamp set and the resultant current produced in each set. The existing LN_2 canister temperature and the fill target are indicated as well, along with the immediate cycle control mode, which is either "heating," "cooling," "dwelling," or "idling at room temperature."

There are also nine auxiliary menu screens to scroll through and view other process indicators or change control parameters. In addition, a screen recapping the thermal extremes of the last 20 cycles can be viewed. Both this recap screen and the menus are viewable while the control program is still running in the background.

These extensive on-screen logistics provide the operator with sufficient information to make sound decisions concerning the operation of the cycler, even from an off-site remote PC. The operator can access the computer from an off-site PC, scroll through menus without program

interruption, and change process control parameters on the fly to optimize cycling performance or correct for aberrant cycler behavior.

5.2 Data Acquisition and Control

The computer acquires data such as heating lamp currents, LN_2 cooling canister levels, solar cell panel temperatures, and the panel's position. Using this information for control feedback, the computer outputs proportionate heating power to the lamps, maintains the cooling shroud temperatures, actuates external devices, and commands a microstepping motor to transport the panel between the top and bottom compartments. The computer outputs analog voltages into proportionate solid-state relays to vary the heating lamp power. Digital outputs from the computer trigger solid-state relays to actuate external devices such as gas purge solenoids, LN_2 bellows valves, and fail-safe hardware relays.

The solar cell panel position is constantly examined by the computer, regardless of the cycling mode. During panel positioning, the motor excursion is monitored to sense stalls or any motion irregularities, while at all other times the panel is checked to verify proper positioning. Stalls, motion irregularities, and improper panel positions will remove power from the motor controller, and a counterweight will return the panel to the "home" position in the top chamber, where the lamps are on at low power to keep the panel warm. In the event of any kind of failure, hardware independent of the computer removes power to all external processes, safely terminates the test, and notifies the operator.

5.3 Archiving Test Data

During the test, data files are generated that provide an archived log of every cycle's general behavior. This log includes the maximum and minimum temperatures encountered for each TC for every cycle. The "Max-of-Max" and "Min-of-Max" values that are a representation of the temperature distributions at the heating extreme are archived for each cycle, along with the "Max-of-Min" and "Min-of-Min" values for the cooling extreme.

In addition, at select cycles, all panel temperatures and dwell phase current test data are captured every 3 sec throughout an entire cycle and stored in a file for later plotting. Figure 6 illustrates such a plot of temperature vs time for cycle No. 25000, while Figure 7 is a graph of the thermal rate for the same cycle derived from the file's data. Note that the maximum rate for that particular cycle was less than 75°/min. Figures 4 and 5 are the plots of a bypass diode test and a current test also derived from these file data.

5.4 Process Monitoring and Alerting

It is desirable not only to characterize the thermal cycling for evaluation after the fact, but also to prevent or alert the operator of aberrations during the test. Therefore, the control program checks for anomalies and failures continuously throughout the test. Among the conditions of concern are temperatures out of range, open control TCs, excessive thermal rates, extended cycle periods, dwell test voltages or currents out of range, and improper panel position.

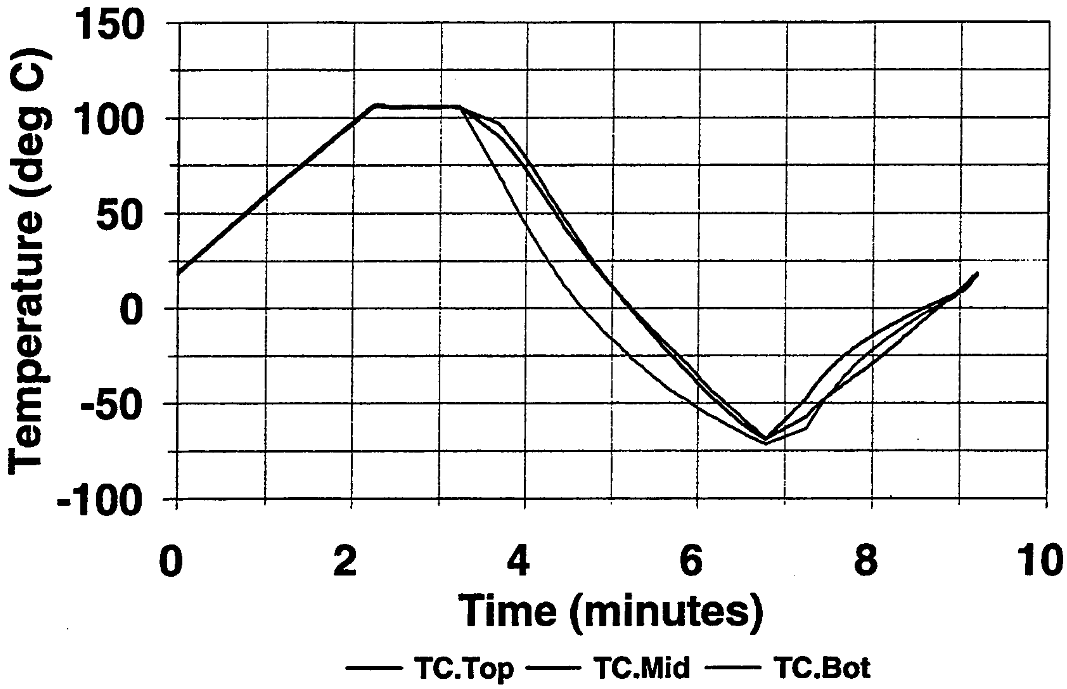


Figure 6. Thermal cycle profiles–cycle 25000.

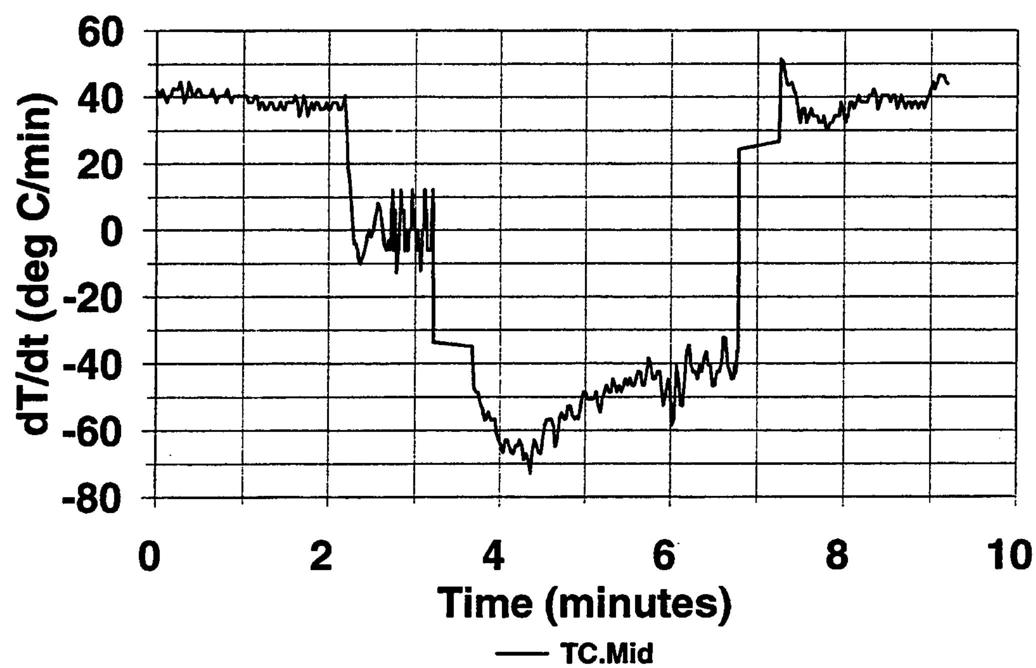


Figure 7. Thermal rate–cycle 25000.

The code responds to an anomaly by saving the status of all indicators at the time of the occurrence to a dedicated notepad file, and initiating an automatic telephone call-out to alert the operator of the anomaly. The cycling, however, is allowed to continue uninterrupted.

In response to circumstances that the program deems to be indicative of a failure, not only is the anomaly response taken, but also the cycling is terminated, and the system assumes a safe idle mode of operation. In the event of catastrophic failures not initiated by the computer such as computer latch-up or power loss, dedicated hardware on UPS back-up power automatically orchestrates a safe shutdown and triggers a telephone call-out.

5.5 Performance Evaluations

At various times during the life test, and at its completion, the solar cells are removed to undergo extensive electrical performance evaluation tests. These tests are conducted at the Aerospace Photovoltaic Engineering Facility in the X25 solar simulator. The tests provide quantitative cell efficiency comparisons at specific cycle lives with initial baseline data.

6. Hybrid Facility Usage To Date

The first test to be run in the new, fast cycler at Aerospace, with solar cells for a program, was on 30 January 1997. The objective of the test was to attain the thermal cycles corresponding to an operational life span to verify mission survivability. Of particular interest was the viability of the welded wire interconnects on the cells, as well as possible cell performance degradation. However, the acquisition of the mandated cycles before the launch deadline necessitated using accelerated cycling rates. The new hybrid cycler was brought into full operation, and the cycles were acquired before the deadline, substantiating that the welded interconnect cells would survive long enough to fulfill their intended mission.

Another test was conducted in this cycler on 22 April 1997. During the first thermal cycle of this test to qualify a new solar panel design, a Teflon film delaminated from the back of the panel. Because of this delamination, a design modification was made using white paint in place of the Teflon film on the actual flight article.

Currently, extended life tests are in progress in both Aerospace fast cyclers. The tests are being conducted for a third program in order to qualify a new solar cell design. For these tests, the capability was developed for in-situ cell and interconnect integrity checks. To date, one cycler has acquired more than 25,000 cycles, and the other, in excess of 10,000 cycles. The thermal cycling extremes are +106°C to -69°C for both tests. The cycle periods are extended to just under 10 min, as requested by the customer, to avoid exceeding their designed safe panel thermal rates. The potential 5 min cycling capability of the cyclers exceeded their maximum allowable thermal rates in both the cooling and heating phases.

7. Conclusions

A new approach for optimizing cycling rates for solar cell thermal cyclers was developed and successfully implemented in two new cyclers, which have since proven themselves in actual operation. Since both the heating and cooling phase rates in these new cyclers can exceed the customer's designed maximum allowable rates, the practical cycling rate limit for these solar panels has been achieved for a gaseous nitrogen environment. This capability makes these cyclers the best choice for fast life tests in which the effects of a vacuum environment on cell survivability are not an issue or are not of interest. The ongoing tests continue to furnish mission design and confidence data to a number of programs, providing a valuable technical database for incorporating advanced higher efficiency solar cells into new generation spacecraft.

An Appendix has been added that contains operating procedures and several control loop diagrams.

Appendix

Procedures and Operation

Start-Up Procedure
for
130-1840 DunkCyc II
Thermocycling Facility

To initiate a test with new solar cells, perform the following sequence:

1. Install specimen and ring out thermocouples (TCs).
2. Align motor train; confirm motor travel to top and bottom positions.
3. Check SOLA and Topaz uninterruptible power supply (UPS) operation and set Variac at 8 for back-up lamp power.
4. Ensure that lamps are operational, with appropriate currents for displayed digital to analog converter (DAC) values.
5. Check Oxygen sensor for proper operation.
6. Seal insulated box and turn on GN_2 purge to drive out moisture in apparatus.
7. Purge in "Idle" mode for at least 10 min.
8. While purging, verify the PC modem communication link with a remote PC, and set up the appropriate Sensaphone call-out sequence.
9. Turn on LN_2 bellows valves heater, cable heater Variac, boil-off controller, and LN_2 fill bag purge.
10. Before initiating thermocycling process, start the LN_2 fill while the cycler is still in "Idle" mode.
11. To begin cycling, proceed to "Operating Procedure" checklist.
12. **Caution**: Always ensure that the KA switch on the control panel is "ON" when left unattended.

Operating Procedure for 130-1840 DunkCyc II Thermocycling Facility

To enter the operational thermocycling mode, perform the following sequence:

1. Perform start-up checklist as outlined in "Start-up Procedure."

2. While still in "Idle" mode, interrogate menus (Press "V" on keyboard to view menu windows), and set desired control options. (Press "A" to alter menu parameters in window.)

3. Set front panel "LN2 Fill" switch to "AUTO" and allow LN2 canister to fill to the target temperature before proceeding.

4. When ready, initiate cycling by pressing "C" and following instructions to enter "Cycle" mode.

5. Note: All control settings can be altered "on the fly" while cycling via the menus, but use caution not to enter menus near the heat/dwell/cool transitions, and return from altering the menus within 15 sec so the KA fail-safe does not time out.

6. Immediately following the first panel transition to the very bottom position, access the "PassWord Menu" on the fly and toggle choice #11 to "3838," returning to the main screen as soon as possible.

7. **Caution**: Always ensure that the KA switch on the control panel is "ON" when left unattended. For typical unattended operation use the following hardware switch and menu settings: 5710 ADC panel "Alarm" switches set to "UP," "PassWordMenu" item #10 toggled to 1, LN_2 Fill switch set to "AUTO," fail-safe Variac set at 8, Sensaphone light set to "ON."

8. To terminate cycling at any time, press "I" and follow instructions to enter "Idle" mode, where the program will automatically position the panel and control the lamps appropriately to maintain the integrity of both the equipment and the cells under test.

9. To terminate the test and totally shut down the facility, perform the sequence outlined in "Shut-Down Procedure."

Shut-Down Procedure
for
130-1840 DunkCyc II
Thermocycling Facility

To terminate the test and totally shut down the facility, perform the following sequence:

1. If cycling is in progress, press "I" and follow instructions to enter "Idle" mode, where the program will automatically position the panel and control the lamps appropriately to maintain the integrity of both the equipment and the cells under test.

2. Turn off LN2 bellows valves heater, cable heater Variac, boil-off controller, and LN2 fill bag purge.

3. Wait in "Idle" mode until solar cell temperatures are stabilized at ambient.

4. Make sure the lamp fail-safe Variac is set at 8; then switch off the KA strip power.

5. Switch off the "UTILITY" strip power.

6. Wait until all facility temperatures are stabilized at ambient; then turn off the fail-safe Variac. The facility can be safely left in this mode indefinitely.

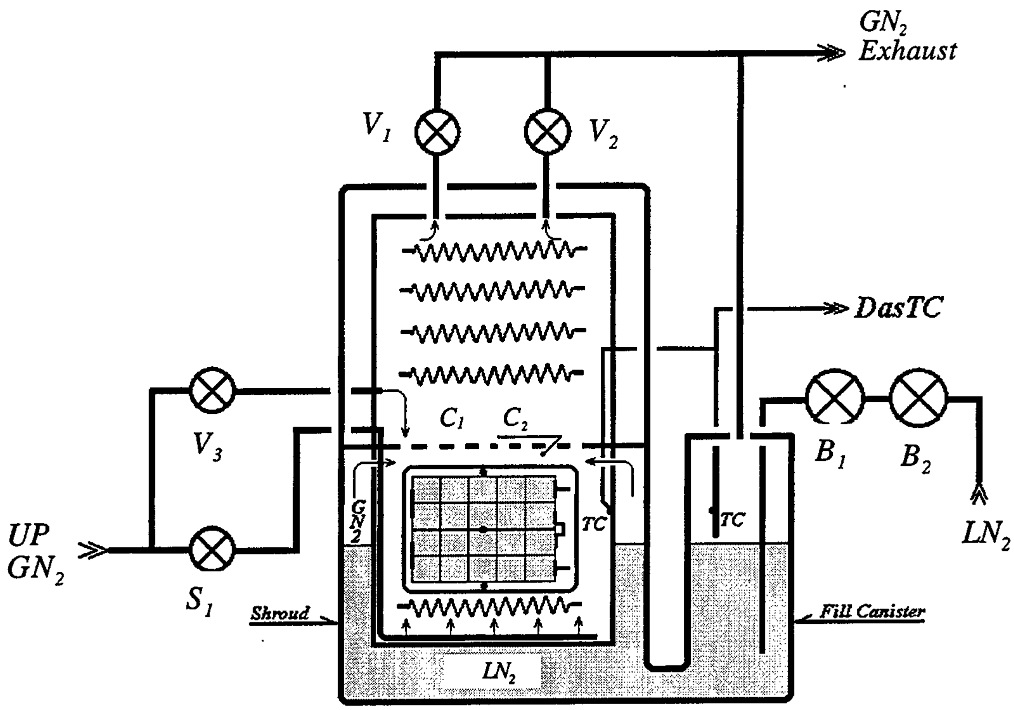
7. **Caution**: Do not open the insulated box until all temperatures are at ambient or higher!

Emergency Shut-Down Procedure
for
130-1840 DunkCyc II
Thermocycling Facility

To immediately shut down the facility, perform the following sequence:

1. Make sure the lamp fail-safe Variac is set at 8; then switch off the KA strip power.
2. Switch off the "UTILITY" strip power.
3. Turn off LN2 bellows valves heater, cable heater Variac, boil-off controller, and LN2 fill bag purge.
4. Unless all facility temperatures are stabilized at ambient, do not turn off or disable the fail-safe Variac. Just leave it on, but no higher than at 8. The facility can be safely left in this mode overnight.
5. **Caution**: Do not open the insulated box until all temperatures are at ambient or higher!
6. Consult the regular "Shut-Down Procedure" before proceeding.

Chamber Overview and Provisions

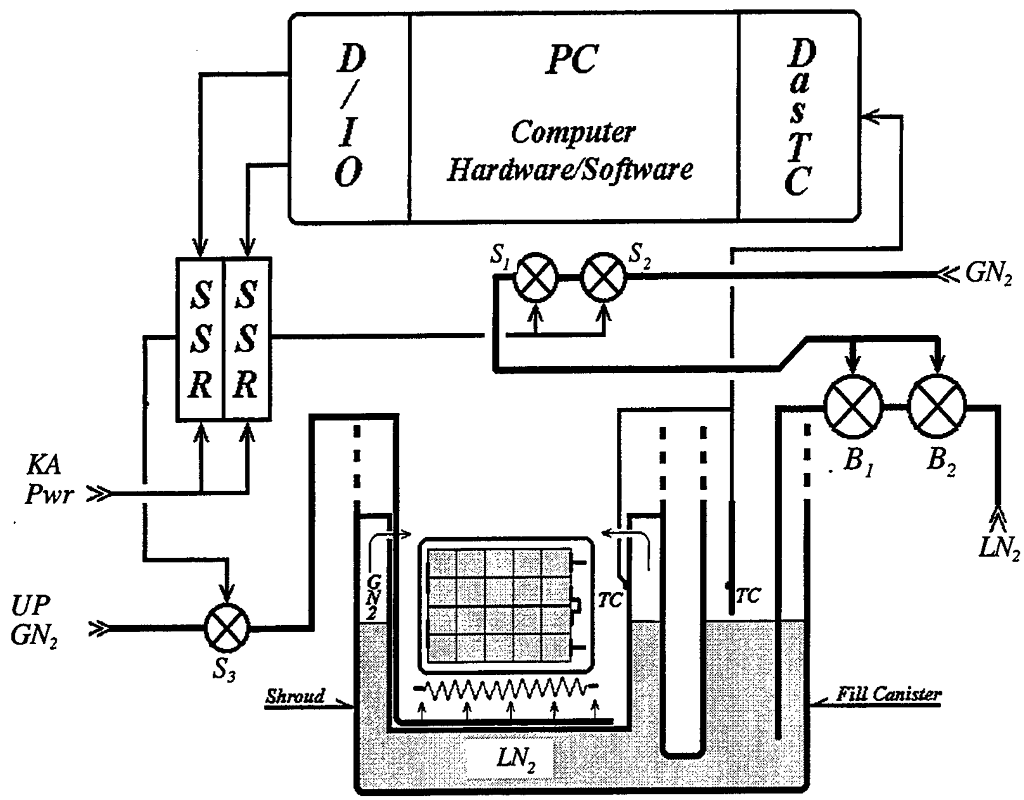


V_1 and V_2:	Manual valves to regulate chamber gaseous nitrogen exhaust flow.
DasTC:	TC Data Acquisition System; reads shroud, fill canister, and solar panel TCs.
LN_2:	Liquid nitrogen; used for cooling solar panel in lower cooling compartment.
UP GN_2:	Ultrapure gaseous nitrogen; used for nitrogen atmosphere purge in chamber.
V_3:	Manual metering valve; provides constant nitrogen purge into upper compartment.
S_1:	Solenoid valve; provides mixing purge during cooling in lower compartment.
B_1 and B_2:	Liquid nitrogen bellows valves; gas operated.
C_1:	Chamber heating compartment–the entire upper half of the chamber.
C_2:	Chamber cooling compartment–the entire lower half of the chamber. The solar panel is shown in the cooling phase position.
GN_2 exhaust:	The nitrogen gas is removed from the lab through a roof vent.

Chamber Facility Provisions

1. Oxygen alarm (not shown).
2. Gassifier (not shown) with exhaust line to roof vent.
3. Liebert Datamate air conditioner (not shown).
4. SOLA 3.0 KVA UPS (not shown) for "clean" PC and instrumentation power.
5. Liquid nitrogen supply from 3000 gal capacity tank (not shown).
6. 40 psi ultraclean gaseous nitrogen from 3000 gal LN_2 tank gassifier.
7. 110 psi GN_2 from compressor and back-up VGL tanks (neither shown) to operate the LN_2 bellows valves B_1 and B_2.
8. 4-30 A 115 VAC circuits dedicated to the four sets of quartz halogen IR lamps.
9. 3-20 A 115 VAC circuits providing "dirty" power for solenoids, solid-state relays (SSRs), relays, Variacs, and other external process loads.

LN_2 Fill and GN_2 Purge Control



D/IO:	Digital input/output; used for digital logic control of external processes.
DasTC:	TC Data Acquisition System; reads shroud and fill canister TCs.
SSR:	Solid-state relay; passes 115 VAC when triggered with DC logic level.
KA Pwr:	Power present if no "failures" have occurred.
LN_2:	Liquid nitrogen; used for cooling.
GN_2:	Gaseous nitrogen; used for actuating LN_2 bellows valves.
UP GN_2:	Ultrapure gaseous nitrogen; used for nitrogen atmosphere purge in chamber.
B_1 and B_2:	Liquid nitrogen bellows valves; gas operated.

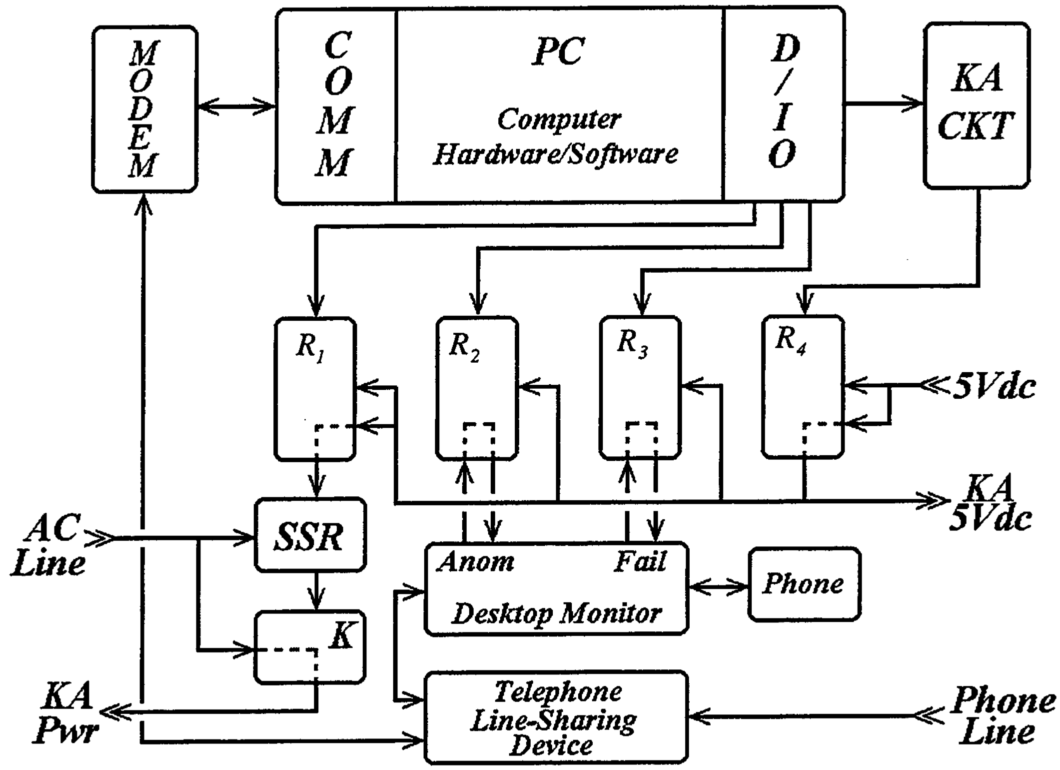
Operation

To perform liquid nitrogen fills, the computer outputs a digital logic level to energize a solid-state relay. This in turn energizes solenoid valves S_1 and S_2, passing gas. The nitrogen gas then actuates the LN_2 bellows valves B_1 and B_2, allowing liquid to enter the fill canister and the shroud. Two solenoid valves and two bellows valves are used on the LN_2 fill to prevent fill runaway in case any valve fails open. TCs on a probe in the fill canister and on the shroud provide feedback to the computer for fill control. As the LN_2 gassifies, the gas is routed through strategically placed holes located in the top of the cooling chamber, as pictured. This cold gas and the cold walls of the shroud cool the solar panel.

To turn on the nitrogen purge, solenoid valve S_3 is energized, allowing ultrapure gaseous nitrogen to be distributed uniformly from a manifold mounted in the bottom of the cooling chamber. This maintains a homogenous thermal mixture and slightly pressurizes the chamber to keep moist air out. The lamp pictured just below the solar panel is used to compensate for thermal gradients across the panel, and is controlled in the same manner as depicted in the "Typical Lamp Control Loop" page.

In the event of a loss of keep-alive power due to a hardware- or software-triggered failure, power is removed from both SSRs so that the GN_2 purge and LN_2 fill are immediately disabled.

Alert Call-Out and Failure Response Systems



MODEM:	A high speed modem; allows remote access to the PC via a phone line.
COMM:	Communications RS-232 serial port in the PC; interfaces to the modem.
D/IO:	Digital input/output; used for digital logic control of R_1–R_4 and KA Ckt.
KA CKT:	The keep-alive circuit; requires a pulsed output from the PC in order to enable R_1–R_4 for normal operation.
AC Line:	115 VAC line power to be routed to all external processes.
SSR:	Solid-state relay; energizes relay K when R_1 is enabled.
K:	Mechanical relay; passes 115 V AC line power to all external processes.
KA Pwr:	Keep-alive power; present if R_1 has been enabled; for all external processes, such as lamps, solenoids, relays.
5Vdc:	Digital logic voltage from an isolated power supply on UPS backup.
KA 5Vdc:	Digital logic control voltage; present only if the KA Ckt is enabled.
R_1:	Digital logic level relay; enables KA Pwr to external devices.
R_2:	Digital logic level relay; triggers anomaly call-outs from the desktop monitor.
R_3:	Digital logic level relay; triggers failure call-outs from the desktop monitor.
R_4:	Digital logic level relay; passes KA 5Vdc control voltage when KA Ckt is enabled.

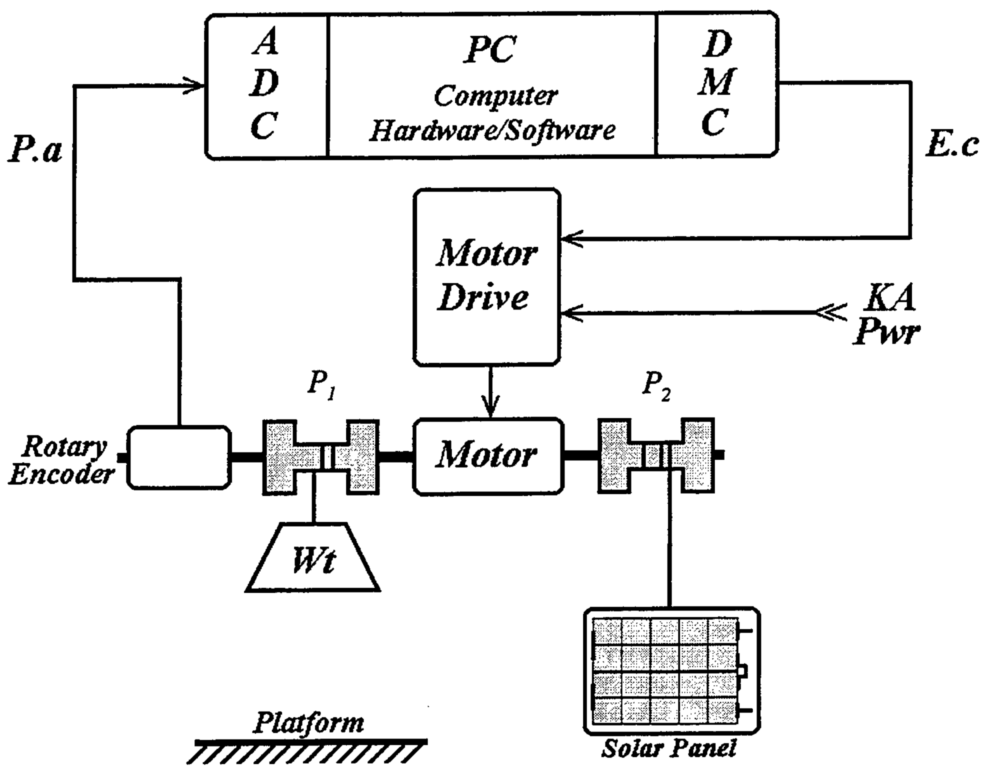
Operation

The system is designed to respond to failures by shutting off all external processes and notifying appropriate personnel. At the heart of the failure response system is the keep-alive circuit, which must receive a digital pulse from the PC at least once every 30 sec to remain enabled. If this does not occur, then a sequence is initiated that removes external process power by de-energizing mechanical relay K. The sequence also triggers an automatic anomaly and failure call-out from the desktop monitor by disabling R_2 and R_3. This failure could be caused by a computer software or hardware latch-up or by unexpected termination of the control program.

In addition, the failure response system allows the PC control program to directly trigger an anomaly or failure call-out and to shut down external process power. This occurs automatically as the result of out-of-range readings in critical processes being monitored.

The alert call-out system not only provides operator notification, but also lets the operator call in to the desktop monitor to hear a status report and listen to the experiment in operation. A telephone line-sharing device automatically routes incoming phone calls to the desktop monitor, but diverts remote PC call-ins directly to the modem. A Terminate and Stay Resident (TSR) program running in the background on the host PC permits a similar TSR program running on a remote PC to control the host via the modem connection. Extensive on-screen logistics allow the operator to make sound decisions about the operation of the facility, even from an off-site remote PC. The operator can access the computer from a home PC, scroll through menus without cycle control interruption, and change process control parameters on the fly to optimize cycling performance or to correct for aberrant behavior.

Microstepping Motor Control Loop

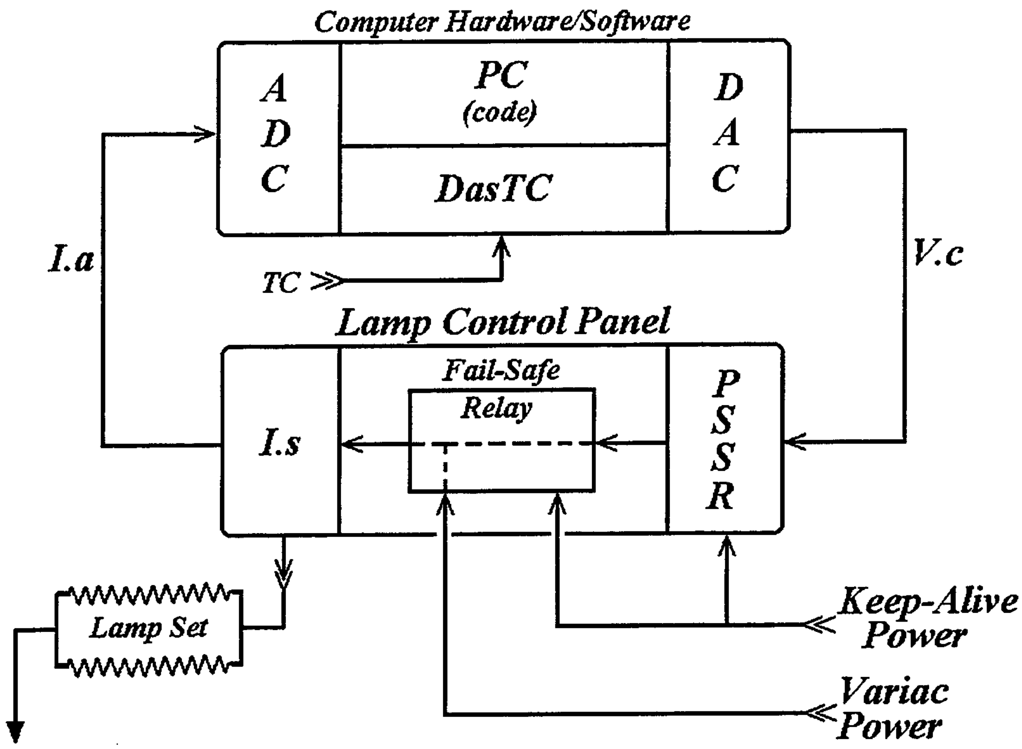


ADC:	Analog-to-digital converter; brings data into computer.
DMC	Dynamic motion control card; controls motor driver.
P.a:	Analog position to computer.
E.c	Excursion control pulses to motor drive.
P_1:	Counterweight pulley.
P_2:	Solar panel excursion pulley.
KA Pwr:	Power present if no "failures" have occurred.

Operation

The computer issues motor excursion commands to the motor driver via the DMC. A rotary encoder provides position feedback information, which the computer compares with the DMC motor pulse counts for agreement. As the solar panel is lowered into the bottom cooling chamber with pulley No. 2, the counterweight is raised off a platform with pulley No. 1. When the counterweight sits on the platform, the solar panel is at the "home" position between the lamps in the upper heating chamber. Any software-triggered failures or hardware faults result in immediate thermal cycling termination. KA power to the motor drive drops, and the counterweight pulls the panel back up into the "home" position, where low lamp power keeps the solar panel warm.

Typical Lamp Control Loop

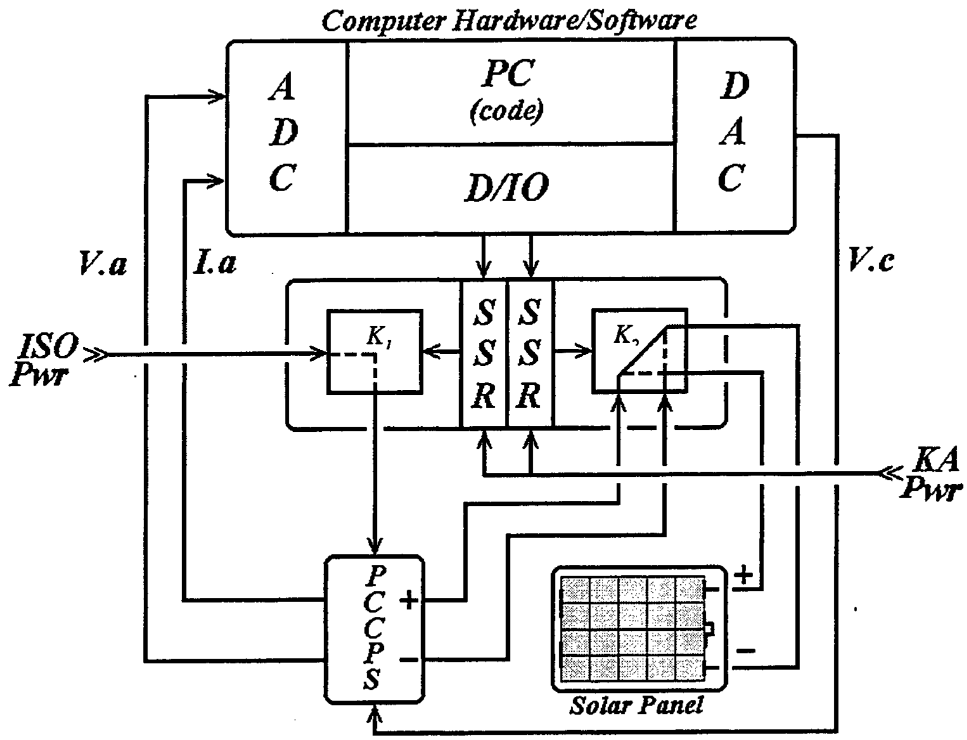


ADC:	Analog-to-digital converter; brings data into computer.
DAC:	Digital-to-analog converter; outputs analog voltage from computer.
DasTC:	TC Data Acquisition System.
PSSR:	Proportionate solid-state relay; provides controllable lamp power.
I.s:	Lamp current sensor; provides analog output.
I.a:	Analog current feedback for control loop.
V.c:	DC analog control voltage; determines PSSR output power.
KeepAlive Power:	Keep-Alive (KA) power; present if no "failures" have occurred.
Variac Power:	Low power from a Variac on a UPS; keeps panel warm.
Relay:	Fail-safe relay; powers lamps with auxiliary Variac power if KA power fails.

Operation

The computer outputs a control voltage to vary the PSSR power to the lamp set using the lamp set's current and the lamp set's TC on the solar panel for control feedback. In the event of a loss of keep-alive power due to a hardware- or software-triggered failure, power is removed from the lamps to prevent thermal runaway, and lamp power is supplied by a back-up Variac. The Variac, powered by a UPS, is set to a very low output to ensure that the solar panel is kept warm (approximately 40°C) without thermal runaway.

Current Test Control Loop



ADC:	Analog-to-digital converter; brings data into computer.
DAC:	Digital-to-analog converter; outputs analog voltage from computer.
D/IO:	Digital input/output; used for digital logic control of external processes.
SSR:	Solid-state relay; passes 115 VAC when triggered with DC logic level.
PCCPS:	Programmable constant current power supply.
V.a:	Analog voltage; represents the voltage across the solar cells.
I.a:	Analog voltage; represents the current through the solar cells.
V.c:	DC analog control voltage; determines PCCPS output current level.
KA Pwr:	Power present if no "failures" have occurred.
ISO Pwr:	Isolated instrumentation power from 3.0 KVA UPS.
K_1:	Relay passing isolated instrumentation power to the PCCPS.
K_2:	Relay reversing the current through the solar cells for bypass diode test.

Operation

In-situ Current and Bypass Diode tests are performed at the top of the thermal dwell phase as often as desired by menu-selectable options. The two tests are identical, except for the direction of current flow and the resulting voltages produced across the solar cell coupons, which are connected in series. The test begins by energizing or de-energizing K_2 for the desired current flow direction with a logic level from the D/IO, triggering K_2's SSR. The PCCPS outputs a current in proportion to an analog input voltage and provides analog output voltages representing the voltage across the coupons and the current through the coupons, V.a and I.a, respectively. These voltages provide feedback for closed-loop control of the PCCPS output. The computer generates a ramped voltage output from the DAC, which ramps the PCCPS current up to the desired 0.200 A in 10 sec, where this level is then held for 10 sec. At this time, the voltage across and the current through the coupons are measured and archived. Then the current is ramped down to zero in 10 sec, completing the test. Loss of KA power, or a software-triggered failure, both result in the PCCPS being powered down to protect the solar cell coupons from current runaway.

TECHNOLOGY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Technology Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual Technology Centers:

Electronics Technology Center: Microelectronics, VLSI reliability, failure analysis, solid-state device physics, compound semiconductors, radiation effects, infrared and CCD detector devices, Micro-Electro-Mechanical Systems (MEMS), and data storage and display technologies; lasers and electro-optics, solid state laser design, micro-optics, optical communications, and fiber optic sensors; atomic frequency standards, applied laser spectroscopy, laser chemistry, atmospheric propagation and beam control, LIDAR/LADAR remote sensing; solar cell and array testing and evaluation, battery electrochemistry, battery testing and evaluation.

Mechanics and Materials Technology Center: Evaluation and characterization of new materials: metals, alloys, ceramics, polymers and composites; development and analysis of advanced materials processing and deposition techniques; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; spacecraft structural mechanics, space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena; microengineering technology and microinstrument development.

Space and Environment Technology Center: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing, hyperspectral imagery; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; component testing, space instrumentation; environmental monitoring, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, and sensor out-of-field-of-view rejection.